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Agricultural Memorandum No. 341

A Comparison of Temperature Indices for the Development of Maize

by Dr M. Hough

Introduction

Agricultural Memorandum No. 332 suggested some possible models for assessing maize growth and development. This memorandum presents the results of two of these models when applied to data from the maize trials at Wytham, Oxford. 8 years data (1962-1969) are used with two trials per year of variety Inra 200, (see Bunting (1968) for growing details). Temperature is the only variable used which is accumulated on a daily basis according to a linear or parabolic law (equs. 1 and 2 in Ag. Mem. 332). The stages 'emergence to flowering' and 'sowing to emergence' are first treated separately and then combined for the 'sowing to flowering' development.

This Memorandum presents results with calculations in different ways; results are given in terms of mean totals and extreme range; clearly the smaller the value of the ratio Range/Mean, the better.

Emergence-Flowering

1. Linear Model

Growth was assumed to commence at 50°F and proceed linearly as temperature increased. Three methods were used:

(a) For each day, 50°F was subtracted from the mean ($\frac{1}{2}$ (max. + min.)) air temperature, and the daily totals were summed over the period.

Mean value = 624°F-days. Extreme range = 261.2°F-days. (746.3 to 485.1)

Range/Mean % = 41.9%.

(b) Degree days were found using maximum and minimum temperatures for each day, (M.O. form 3300), and summed.

Mean = 659°F-days. Extreme range = 208°F-days. (755 to 547).

Range/Mean % = 31.6%.

(c) The third method involved estimating the mean temperature during the daylight hours. This temperature was considered more suitable than the day and night temperatures as used in (a) and (b), since photosynthesis and most growth occurs during the daylight hours.

The mean daylight temperature (M) was obtained by assuming a sinusoidal daily variation of temperature, and with the daylight period from the time of minimum temperature to when the temperature fell to the day mean temperature during the evening. It is given by

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$M = \bar{T} + 0.106\ (T_{max} - T_{min})$.

$\bar{T}$ = day mean temperature ($\frac{1}{2}$(max + min)), T_{min} = minimum temperature, T_{max} = maximum temperature.

When M had been found, 50° was subtracted and the total of daily values was obtained.

Mean = 746°F-days. Extreme range = 265.6°F-days (858.0 to 592.4).

Range/Mean % = 35.5%

This model is only slightly better than (a) and worse than (b). A refinement was made to (c) by calculating M only when the temperature was above 50°F. This is done assuming that no growth occurs when the temperature is below 50°F even though the plants may be in the light. The modified form of (c) was applied to the two extreme years. An improvement of about 5% in the variability was obtained and so it did not seem worth while to apply the model to the other years. Further refinements could be made to (c), e.g. to allow for the actual daylength variation from the end of May to the beginning of August, and to include the effect of temperatures on the following day, but these have not been considered.

2. Parabolic Model

Growth was assumed to start at 50°F, reach a maximum rate at 86°F and then to decrease. The daily contribution is calculated from $(T-50) - \frac{1}{72}(T-50)^2$, where T = temperature in $^{\circ}$F.

(a) Mean daylight temperature M, used for T.

Mean = 616.0. Extreme range = 198 (706.9 to 508.9). Range/Mean % = 32.1%.

The variability was improved to about 26% when the more precise value of M was used, mentioned in 1(c) above.

(b) Screen maximum temperature used for T.

Mean = 1,649.0. Extreme range = 246.8 (1,741.2 to 1,503.8) Range/Mean % = 15%.

This is an improvement on the linear models. It is also better then 2(a) which uses M for T. This is interesting and may mean that the maximum temperature measured at screen height is in high correlation with the mean plant (or leaf) temperature throughout daylight hours.

(c) Model 2(b) just discussed is the daytime part of Brown's (1969) method for assessing corn development. The night contribution to growth is found by accumulating $(T_{min} - 40)$ where T_{min} $^{\circ}$F is the minimum temperature.

Brown's method gives:

Mean = 1228.0. Extreme Range = 263.8 (1,356.8 to 1,093.0) Range/Mean % = 21.4%.

This is an improvement on any linear model, but still worse than 2(b).

Much previous work on maize has stressed the importance of moisture conditions near flowering time. Lack of water at this time can hinder the

/development

development of flowers. Figure 1 shows the temperature index for the emergence - flowering period, using the screen maximum temperature in the parabolic law, plotted against rainfall during the week preceding flowering. The rainfall was obtained from the Radcliffe Observatory, Oxford, about 4 miles from the trial grounds.

The graph shows a lot of scatter, but this can be improved. If 8 days rainfall is considered then point A becomes A^1. For points B and C nearly all the rain fell during the 4 days preceding flowering and before this there were 2 weeks of dry weather. It is quite possible that the plants were nearly flowering before the rain fell, so that B, C ought to be plotted more to the left in a drier régime. If these adjustments are accepted then there is a negative correlation between the temperature index (2b) and rainfall near flowering time. It is inferred from this that when the plants reach a critical stage, development can be retarded by lack of rain.

This index was also plotted against rainfall during the previous 2 and 3 weeks before flowering, but poorer relationships were found. This could be due to the maize being less sensitive to rain or because the actual rainfall at the trials was diverging more and more from the Radcliffe figures during the sampled years.

Sowing - Emergence

The factors affecting germination include soil moisture, temperature and soil oxygen, but only temperature is used here. Soil temperatures at 2 in. depth were available at the trial site and are used in linear and parabolic laws as previously.

1. Linear Model

Chirkov (1965) suggests that 46°F is the base temperature at seed depth for germination of maize seeds, and this value is used here.

(a) Day degrees above 46°F were found using M.O. 3300 and totalled for days from sowing to emergence

Mean = 149°F-days. Extreme Range = 88°F-days (198 to 110). Range/Mean % = 59%.

Planting depth was 5 cm in the trials and Chirkov gave a value of 162°F-days for this depth with plentiful soil moisture($\geq$ 15 mm. moisture in the first 10 cm of soil).

2. Parabolic Model

Germination was assumed to begin at 46°F and to increase to a maximum rate at 80°F. This last figure is very approximate and interpolated from a table in Wang, Jen-Yu (1963). Each daily contribution was calculated from $(T-46) - \frac{1}{68}(T-46)^2$, where T = temperature °F.

(a) T is set equal to the mean ($\frac{1}{2}$ (max. + min.)) day temperature.

Mean = 116.0. Extreme range = 83.5 (162.8 to 79.3). Range/Mean % = 72%.

This is worse than the linear model.

/Robertson

Robertson (1968) has shown that the germination of Marquis wheat depends upon maximum and minimum temperature (measured in the screen) according to a parabolic law. This was tried for maize using maximum and minimum soil temperatures separately in the above model.

(b) Maximum soil temperature alone.

Mean = 204.0. Extreme range = 124.1 (268.5 to 144.4). Range/Mean % = 61%.

(c) Day and night contributions added.

Mean = 226.0. Extreme range = 123.8 (303.3 to 179.5). Range/Mean % = 55%.

There is little to choose between any of the models suggested here, and none describe germination development well. The moisture supply to the seed would presumably also be important since water has to be absorbed before sprouting can occur. A dry soil would not give rapid germination even though temperatures were favourable and these years ought to have high values of temperature index. A general idea of rainfall and sunshine prior to and after sowing was obtained using Radcliffe data.

The years with high values of temperature index had dry weather before sowing while wet weather made for rapid germination (see table below; two sowing dates each year).

Year	Number of consecutive dry days immediately before sowing	Weather on sowing day	Number of consecutive dry days immediately after sowing	Index 1(a) (linear modol °F days)	
1962 (i)	7	dry	1	190	
(ii)	8	dry	0	198	(highest)
1963 (i)	3	dry	1	190	
(ii)	0	rain	0	147	
1968 (i)	0	rain	0	110	(lowest)
(ii)	1	dry	0	119	

Such an approach can only separate gross differences, better estimates of soil moisture might improve the relation.

The depth of seed placement could also explain some of the year to year variability. Chirkov suggests that an extra 12.6°F-days are required for each 1 cm increase in sowing depth. The depth was 5 cm for the trials, but quite small surface irregularities could produce an error of 1 cm in this depth.

Sowing - Flowering

An index for sowing to flowering development was obtained by adding the indices for the stages sowing - emergence and emergence - flowering.

1. Linear Model

Add °F days above 46°F for 2" soil temperature and °F days above 50°F for screen temperature.

Mean = 809°F-days. Extreme range = 163°F-days (898 to 735). Range/Mean % = 20.1%

/2.

2. Parabolic Model

(a) Maximum 2" soil temperature (model 2(b) in sowing-emergence), and maximum screen temperature (model 2(b) in emergence-flowering).

Mean = 1,854. Extreme Range = 225.7 (1,976.6 to 1,750.9). Range/Mean % = 12.2% .

(b) Screen maximum temperature (model 2(b) in emergence-flowering) and maximum/minimum 2" soil temperature (model 2(c) in sowing-emergence).

Mean = 1873.0. Extreme range = 202.4 (1,991.5 to 1,789.1). Range/Mean % = 10.8%.

The variabilities of the combinations are smaller than those of the individual components. This seems to be explicable by the existence of a negative correlation between the temperature indices for sowing-emergence and emergence-flowering (see Figure 2). From the graph, only 1964 does not follow the general trend. Because of this correlation even the linear degree day model has done quite well for sowing-flowering (20% variability). The parabolic laws, which do at least allow for an optimum in the growth-temperature relation, are better (11% and 12% variability), then the linear model.

Summary

When temperature alone is used as an indicator for development, varying degrees of success are obtained depending on the growth stage. For sowing to emergence there is only a weak temperature dependence with little difference between linear or parabolic models. Robertson's (1968) idea which uses maximum and minimum temperatures separately in parabolic laws is the best, but it is difficult to think of reasons for this response. Other factors such as soil moisture are probably more important.

The temperature dependence is strong from emergence to flowering and parabolic laws do better than linear models. Even so the choice of temperature to be used in the model is very critical. Plant, or leaf, temperature must have the greatest bearing on development and it may be possible that the screen maximum temperature bears a reliable relationship to the average daylight plant temperature, since maximum temperature gives the best index. Rainfall also seems to have a bearing on development and Figure 1 showed that large emergence-flowering indices may be due to lack of rain just before the flowering stage, while Figure 2 indicates that a small sowing-emergence index has the same effect. Dry conditions during early growth (and so a large germination temperature index) may encourage a more extensive root system then wet conditions. This in turn may lead to more rapid development later on, resulting in a lower emergence-flowering temperature index. On the other hand, a long germination period may permit some bio-chemical process to occur which favours more rapid development later on.

Any comments or suggestions on this paper should be sent to the author.

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Meteorological Office
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Berks.

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FIGURE 1

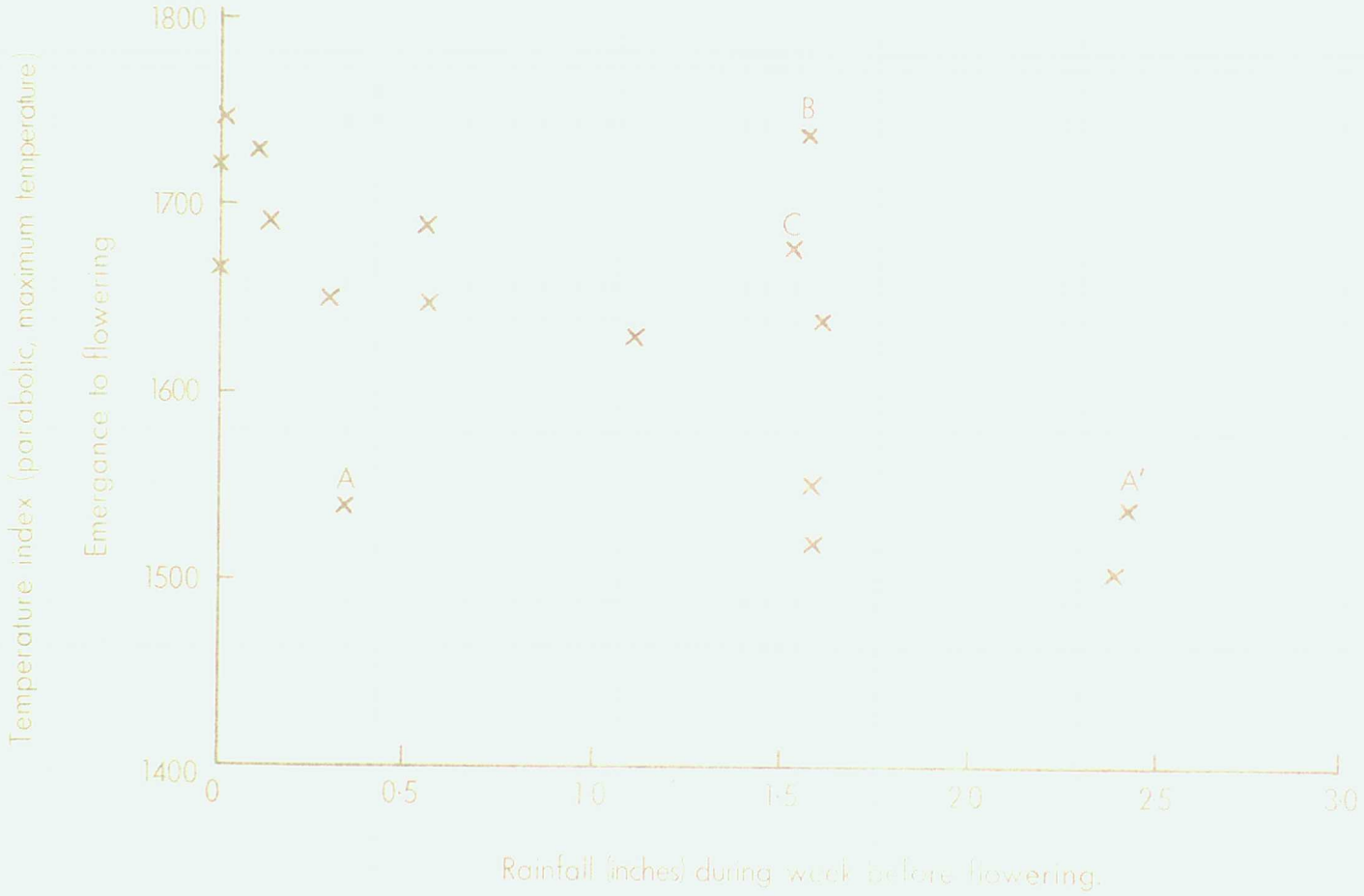
Temperature index (parabolic, maximum temperature)
Emergance to flowering
1800
1700
1600
1500
1400
0
0·5
1·0
1·5
2·0
2·5
3·0
A
A'
B
C
Rainfall (inches) during week before flowering.

FIGURE 2

The bracketed number refers to different sowing dates during the year.